A COMPARISON OF THE ACCURACY OF OBJECTIVE TECHNIQUES FOR FORECASTING TYPHOON MOVEMENT DURING 1967

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ABSTRACT

In the past, many objective techniques have been evaluated for severe tropical cyclones in the Atlantic, but little has been done along this line in the Pacific. A computer program was developed at the Joint Typhoon Warning Center, to verify 10 separate 24-hr. forecast techniques. During the course of the 1967 season, a total of 14 different techniques were tested on 27 tropical cyclones. All techniques were adjusted to facilitate direct comparisons with the official Joint Typhoon Warning Center (JTWC) forecasts. Most methods were tested on an operational basis. All forecasts initially used operational positions with final verifications made against the tropical cyclone's best track. Although direct comparisons between the methods are difficult due to inhomogenity of sample size and differences in storms tested, all statistics and comparison figures are made against the official forecast using the same cyclones in the sample. After several storms, it became apparent that superior results were being obtained from computer steering predictions received from Fleet Numerical Weather Facility (FNWF), Monterey, Calif. After concentrating on these steering predictions and modifying them following a technique developed by Professor R. J. Renard, a final operational technique was developed called the Monterey 700-mb. A Modified. This forecasting method has shown far superior results to any other operational objective technique tested and is comparable in accuracy to the official JTWC forecast.

1. INTRODUCTION

Few statistics have been compiled concerning the merits of the various forecast methods for tropical cyclones in the Pacific. If a number of forecasts are prepared by the various methods, the Typhoon Duty Officer (TDO) is confronted with a wide divergence of forecast tracks. Unless it is known which method is superior in a given situation, little or no weight is given to any of the objective systems. With this in mind, a study was undertaken to evaluate a large number of objective techniques for forecasting tropical cyclones under operational conditions using numerical methods.

Two sets of logs were kept on all storms. The best track log was completed following dissipation of each tropical cyclone. The best track of a cyclone is a post-analysis summary (using reconnaissance, satellite, radar, and weather chart information) giving cyclone locations, intensities, and directions and speeds of movement. The 24-hr. objective forecast log was filled out by the TDO as the various forecasts were made. The logs were double checked for accuracy and the data cut on Hollerith machine cards. The data card information was read into the computer, processed, and printed using the online printer.

The computer program used in the verification of the various objective techniques is such that one or multiple storms may be run at any one time. Examples of the two printouts produced by the program are shown in figure 1. The first printout (fig. 1a) gives a summary for each individual tropical cyclone. For each individual technique the following information is listed: the verification time, the vector error from the best track position to the forecast position, and the average 24-hr. forecast error. The second printout (fig. 1b) provides a summary for all the cyclones and lists the following information for each technique: the number of cases and the average 24-hr. forecast error when the maximum best track winds at the forecast time are less than 50 kt., the number of cases and the average 24-hr. forecast error when the maximum best track winds at the forecast time are 50 kt. or greater, and the average 24-hr. forecast error for all wind intensities. The program can be easily altered to change the 50-kt. intensity to any intensity desired.

To enable a direct comparison of the various objective techniques with the official forecast under operational conditions the following procedures were incorporated. The verification times were chosen at 0600 and 1800 GMT to facilitate using the latest 0000 and 1200 GMT upper air charts. Reconnaissance fixes are normally taken 2 hr. prior to warning time (0400, 1000, 1600, and 2200 GMT). After receipt of the fix at JTWC, this position is then used on the 0000, 0600, 1200, and 1800 GMT warnings. This extrapolated position was also used as a base for the various objective techniques. Therefore, in terms of reconnaissance fixes, a 24-hr. forecast is in reality a 26-hr. forecast (2-hr. extrapolation plus the 24-hr. objective forecast). All intensities of tropical cyclones were verified (tropical depressions, tropical storms, and typhoons).

24 HOUR OBJECTIVE TECHNIQUES VERIFICATION DATA
TROPICAL CYCLONE 32

a

DTG	JTWC DEG DIST	MTRY 7 AM DEG DIST	MTRY 5 PM DEG DIST	MTRY 7 A DEG DIST	MTRY 7 PM DEG DIST	MTRY 5 A DEG DIST	EXTRAP DEG DIST	MTRY 1 P DEG DIST	MTRY 7 P DEG DIST	MTRY 5 P DEG DIST
290600Z	267--102	--------	--------	345-- 24	--------	057-- 60	--------	263--132	199-- 36	104-- 90
291800Z	295--192	313--126	277--132	326--108	281--144	0[illegible]0--114	295--192	284--240	281-- 90	0[illegible]4-- 12
300600Z	350--138	347-- 84	052--102	344--132	003--120	--------	357--120	295--318	332--12[illegible]	0[illegible]8--138
301800Z	018--276	014--102	007--114	355--156	335-- 84	063--192	039--198	299--294	329--1[illegible]2	0[illegible]1--192
010600Z	015-- 72	050-- 54	277-- 48	360-- 48	314-- 24	098-- 78	295--108	290--288	308--102	077--126
011800Z	099--102	110--186	123--108	094--150	121--156	107--240	099--204	266-- 78	110-- 48	097--192
020600Z	078--240	077--150	090--186	076--186	077--150	094--306	078--240	04[illegible]-- [illegible]2	077--[illegible]2[illegible]	093--300
021800Z	090--288	081--150	083--132	079--210	0[illegible]1--144	091--324	078--130	05[illegible]--120	073--156	0[illegible]7--300
030600Z	108--108	086-- 72	019-- 54	078--240	093-- 90	079--270	108--108	081--174	074--223	07[illegible]--270
031800Z	136--138	165--114	153--156	094--210	160--138	096--276	150--180	095--120	089--174	090--270
040600Z	168--144	176-- 96	180-- 54	120--234	205-- 72	115--270	168--144	150--144	11[illegible]--15[illegible]	099--27[illegible]
041800Z	188-- 48	171-- 84	230-- 54	138--198	196-- 42	118--258	234-- 30	178--180	133--144	105--252
050600Z	293-- 54	240--150	258--186	180--204	250--216	146--192	238--234	209--318	186--174	134--1[illegible]
051800Z	149--102	219--102	174--132	187--258	187--102	152--240	149--102	221--408	19[illegible]--258	1[illegible]0--234

		MILES
1.	JTWC AVERAGE ERROR	143
2.	MTRY 700 ANAL MOD AVERAGE ERROR (OPER)	113
3.	MTRY 500 PROG MOD AVERAGE ERROR	112
4.	MTRY 700 ANAL AVERAGE ERROR	168
5.	MTRY 700 PROG MOD AVERAGE ERROR	114
6.	MTRY 500 ANAL AVERAGE ERROR	217
7	EXTRAPOLATION AVERAGE ERROR	153
8.	MTRY 1000 PROG AVERAGE ERROR	206
9.	MTRY 700 PROG AVERAGE ERROR	141
10.	MTRY 500 PROG AVERAGE ERROR	201

b

OBJECTIVE TECHNIQUES VERIFICATION SUMMARY FOR ENTIRE YEAR

A. MAXIMUM WINDS LESS THAN 50 KNOTS

		MILES	CASES
1.	JTWC AVERAGE ERROR	135	10
2.	MTRY 700 ANAL MOD AVERAGE ERROR (OPER)	130	5
3.	MTRY 500 PROG MOD AVERAGE ERROR	117	2
4.	MTRY 700 ANAL AVERAGE ERROR	123	8
5.	MTRY 700 PROG MOD AVERAGE ERROR	132	2
6.	MTRY 500 ANAL AVERAGE ERROR	156	6
7.	EXTRAPOLATION AVERAGE ERROR	142	8
8.	MTRY 1000 PROG AVERAGE ERROR	185	8
9.	MTRY 700 PROG AVERAGE ERROR	112	7
10.	MTRY 500 PROG AVERAGE ERROR	132	7

B. MAXIMUM WINDS 50 KNOTS OR GREATER

		MILES	CASES
1.	JTWC AVERAGE ERROR	119	76
2.	MTRY 700 ANAL MOD AVERAGE ERROR (OPER)	133	72
3.	MTRY 500 PROG MOD AVERAGE ERROR	144	47
4.	MTRY 700 ANAL AVERAGE ERROR	157	68
5.	MTRY 700 PROG MOD AVERAGE ERROR	124	47
6.	MTRY 500 ANAL AVERAGE ERROR	203	67
7.	EXTRAPOLATION AVERAGE ERROR	135	67
8.	MTRY 1000 PROG AVERAGE ERROR	178	54
9.	MTRY 700 PROG AVERAGE ERROR	140	59
10.	MTRY 500 PROG AVERAGE ERROR	187	58

C. AVERAGE FOR ALL WIND INTENSITIES

		MILES	CASES
1.	JTWC AVERAGE ERROR	121	86
2.	MTRY 700 ANAL MOD AVERAGE ERROR (OPER)	133	77
3.	MTRY 500 PROG MOD AVERAGE ERROR	143	49
4.	MTRY 700 ANAL AVERAGE ERROR	153	76
5.	MTRY 700 PROG MOD AVERAGE ERROR	124	49
6.	MTRY 500 ANAL AVERAGE ERROR	199	73
7.	EXTRAPOLATION AVERAGE ERROR	136	75
8.	MTRY 1000 PROG AVERAGE ERROR	179	62
9.	MTRY 700 PROG AVERAGE ERROR	137	66
10.	MTRY 500 PROG AVERAGE ERROR	181	65

FIGURE 1.—Examples of the two computer printouts produced by the 24-hr. objective techniques verification program: (a) summary for individual tropical cyclone; (b) summary for all the tropical cyclones during the year.

2. DISCUSSION OF FORECAST TECHNIQUES TESTED

A brief summary of the forecasting techniques tested follows. They are not listed in order of performance.

a) JTWC—The official Joint Typhoon Warning Central, Guam forecast. During the 1967 tropical cyclone season, the official forecast was formulated using subjective methods, and therefore can be considered to be uncontaminated with any objective technique. The JTWC forecasts were used for comparison purposes only.

b) Tse [1]—A method which incorporates the 700-mb. synoptic pattern into the forecast scheme. The differences in the 700-mb. contour heights oriented north-south and east-west are used as the predictors. A nomogram is then entered to give the 24-hr. forecast position.

c) Arakawa [2]—The Arakawa technique uses regression equations to forecast 24- and 48-hr. movement plus intensities. After using a grid overlay, pressures on the latest surface chart are transferred to a worksheet. Simple computations result in the forecast positions.

d) Climatology—The assumption made using this procedure is that a given storm will move in the mean direction and speed of all typhoons that have been located at approximately the same latitude and longitude during that month of previous years. Climatological charts used in this study were compiled by Chin [3].

e) Extrapolation—Extrapolation is a semiobjective method by which the forecast track is determined using past values of speed, direction, and intensity.

f) Monterey 500-mb. HAT—Numerically predicted steerings, "steers," obtained from Fleet Numerical Weather Facility (FNWF), Monterey, Calif., over the computer data line. The program, called HAT, was written by FNWF personnel and uses a grid surrounding the tropical cyclone. The 500-mb. barotropic height prognosis is heavily smoothed in the area surrounding the storm. The cyclone is treated as a point vortex and is advected in 1-hr. time steps up to a forecast period of 72 hr.

g) Monterey 1000-mb. P—Numerically predicted steerings obtained from a program called HATRACK. The program was written by LCDR. B. L. Bradford and LT. G. A. Brearton at FNWF and is still considered to be experimental in nature. There are two versions of the program, the first uses SR prognostic fields and the second uses SR analysis fields. SR fields [4] are constant pressure height fields in which the small-scale disturbances are smoothed out. The storm is advected as a point vortex in the SR fields in 3-hr. time steps up to a forecast period of 72 hr. Steerings were provided at the 1000-, 700-, and 500-mb. levels, but the program can be modified to use any mandatory level up to and including 100 mb. The Monterey 1000-mb. P technique provides steerings using 1000-mb. prognostic SR fields.

h) Monterey 700-mb. P—Numerically predicted steerings using 700-mb. prognostic SR fields.

i) Monterey 700-mb. A—Same as item h, except the latest available analysis field is used for the steerings.

j) Monterey 700-mb. P Modified—A modification of the Monterey 700-mb. P technique using a correction for bias [5]. A detailed description of how corrections were applied is contained in section 3.

k) Monterey 500-mb. P—Numerically predicted steerings using 500-mb. prognostic SR fields.

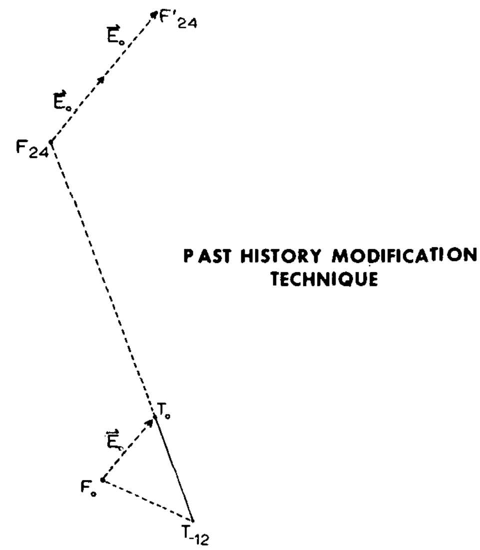
l) Monterey 500-mb. A—Same as item k, except the latest available analysis field is used for the steerings.

m) Monterey 500-mb. P Modified—A technique similar to item j, except 500-mb. prognostic SR fields are utilized in the steerings.

n) Monterey 700-mb. A Modified—A method similar to item j, except the latest available analysis field rather than prognostic SR fields is used. This technique was used *operationally near the end of the typhoon season* because of its timeliness. The prognostic SR steerings, although resulting in superior forecasts, were often not available until after the official warning was issued.

3. DESCRIPTION OF THE MONTEREY SR MODIFIED TECHNIQUE

In the pursuit of a technique for the improvement of the SR forecasts, the method developed by Renard



T_0= Present position of storm from latest JTWC warning

T_{-12}= Position of storm 12 hours previous from reconnaissance reports

F_0= Forecast position of storm from position T_{-12}

$\vec{E}_0$= Vector error for previous 12 hour forecast

F_{24}= 24 hour forecast position from T_0

F'_{24}= 24 hour forecast position of storm with 2 times the past 12 hour vector error applied

FIGURE 2.—Vector diagram illustrating 24-hr. past-history modification technique.

[5] was tested and, with slight modifications, was used. In using a correction for bias in the basic FNWF steering predictions, the assumption is made that forecast errors made in the past will continue to occur in the future. A limited amount of testing using 6-, 12-, and 24-hr. past history corrections was done. The 12-hr. correction appeared to result in superior verifications and was used henceforth. In his studies, Renard [5] found the application of a 24-hr. rather than 12-hr. bias correction yielded the optimum results. A vector diagram depicting the modification technique is shown in figure 2. It is felt that using a 6-hr. history correction is too short a time interval in that operational warning positions frequently exhibit substantial errors. A comparison of distance between operational warning positions and best track positions reveals an average near 30 mi. Multiplication of a 30-mi. error in warning position by 4 for a 24-hr. forecast, would in itself, result in a 120-mi. error. In antithesis, using a 24-hr. past history correction would not reflect the latest changes that have occurred in the upper air patterns. The use of a history modification technique is justified in that it corrects for use of the wrong steering level, using geostrophic rather than actual wind, and errors that have occurred in the prognostic and analysis fields.

4. TESTING AND RESULTS

The procedures outlined in the previous sections were incorporated to predict the 24-hr. movement of the 1967 tropical cyclones in the JTWC area of responsibility. The figures in tables 1 and 2 give average forecast errors in nautical miles and the number of cases used to compute the averages in parentheses. Direct comparisons between the various forecasting techniques are difficult as the sample size was not homogeneous and the life cycle of the storms tested was not always the same. However, all statistics and comparison figures were made using the same cyclones in the sample. When a specific technique was not doing well in comparison with others it was dropped and a different objective technique was substituted for verification; therefore, sample sizes vary considerably. Official forecast verification figures are included in all tables for comparison purposes.

Table 1A depicts three objective techniques: Tse, Arakawa, and Climatology. The Tse technique, although forecasting direction of movement fairly well, appeared to be consistently slow in speed of movement. The Arakawa forecasts did exceptionally well when the atmospheric steering currents were basically consistent up to 500 mb.; however, in cases where this vertical consistency did not exist, large forecast errors occurred. Although Climatology forecast errors were larger than those of any other technique, it still proved to be very useful in the lower latitudes where, frequently, insufficient data were available to use the other techniques to advantage.

Evaluation of the Monterey 500-mb. HAT numerically predicted steerings (table 1B) were discontinued early in the season after ascertaining that the new Monterey HATRACK steerings were doing much better in comparison.

Extrapolation, as shown by table 1C, proved to be one of the best short-range forecasting techniques available. However, being a semiobjective method, a direct correlation exists between forecast errors and forecaster experience. In addition, in the Pacific region, upper air measurements are sparse and in many cases nonexistent regardless of the geographical location of the tropical cyclone. Therefore, in most cases, "educated" extrapolation will result in superior verifications when compared with other techniques that require accurate upper air analyses.

As was previously mentioned in section 2, in most cases, the Monterey SR prognostic steerings were not available until after the 0600 and 1800 GMT warnings were issued. The prognostic steerings were available for use in issuing the 0000 and 1200 GMT warning, but verification figures were not made at those times. Verification results of the Monterey prognostic steerings (table 1D) indicate that overall, the 700-mb. level was the best single steering level by a considerable amount. This is in contrast to Renard's findings [5] which showed the SR 500-mb. level to result in superior verifications in the western Pacific Ocean.

A comparison of Monterey numerically predicted steerings using analyses versus prognostic fields is shown in table 1E. The improvement in the forecasts using prognostic over analyses steerings was near 17 n.mi., but the number of cases involved was relatively small.

TABLE 1.—*Average forecast errors (n.mi.) for various 24-hr. objective techniques. Number of cases in parentheses*

A — Tse, Arakawa and Climatology

Official	166	(193)
Tse	189	(189)
Arakawa	198	(155)
Climatology	212	(149)

B — Monterey 500 MB Hat

Official	176	(96)
Monterey 500 mb Hat	184	(40)

C — Extrapolation

Official	152	(279)
Extrapolation	151	(268)

D — Monterey Prognostic (P) Steers

Official	159	(234)
Monterey 1000 mb P	192	(210)
Monterey 700 mb P	153	(209)
Monterey 500 mb P	173	(200)

E — Monterey 700 MB and 500 MB Anal (A) Steers vs Monterey 700 MB and 500 MB Prog (P) Steers

Official	121	(86)
Monterey 700 mb A	153	(76)
Monterey 700 mb P	137	(66)
Monterey 500 mb A	199	(73)
Monterey 500 mb P	181	(65)

F — Monterey 700 MB and 500 MB Prog (P) Steers vs Monterey 700 MB and 500 MB Prog (P) Modified Steers

Official	153	(173)
Monterey 700 mb P	148	(163)
Monterey 700 mb P Modified	120	(128)
Monterey 500 mb P	181	(160)
Monterey 500 mb P Modified	131	(128)

G — Monterey 700 MB Anal (A) Steers vs Monterey 700MB Anal (A) Modified Steers

Official	118	(75)
Monterey 700 mb A	154	(65)
Monterey 700 mb A Modified	126	(65)

The application of the correction for bias as described in section 3, showed considerable improvement in the Monterey steerings. As noted in table 1F, average errors decreased from 148 to 120 n.mi. for the 700-mb. level and 181 to 131 n.mi. for the 500-mb. level. It seems reasonable that this type of correction could be applied to other objective forecasting techniques, thereby decreasing forecast errors.

Late in the typhoon season, after determination of the best SR steering level and modification made, the

TABLE 2.—*Average forecast errors (n.mi.) in homogeneous sample of forecasts by the best 24-hr. objective techniques. Number of cases in parentheses*

Official	137 (127)
Extrapolation	138 (127)
Monterey 700 mb. P	137 (127)
Monterey 700 mb. P Modified	120 (127)

Monterey 700-mb. A Modified technique was tested under operational conditions. Although the number of cases was again relatively small, the results (table 1G) were comparable in accuracy to the JTWC forecast. It is to be noted that the late 1967 season cyclones were by comparison relatively consistent movers and easily predictable, therefore forecast errors were relatively low.

To better evaluate the merits of the best 24-hr. forecast techniques tested, a homogeneous sample is shown in table 2. The 700-mb. A Modified forecasts were not included because of the small sample size. Table 2 again depicts the relative worth of the Monterey 700-mb. P and the Monterey 700-mb. P Modified forecasts.

5. CONCLUDING REMARKS

Of the 14 tropical cyclone steering methods tested, four showed superior verifications. There were the Monterey 700-mb. P Modified, Monterey 700-mb. P, Extrapolation, and Monterey 700-mb. A Modified.

If the prognostic SR steering predictions can be made available prior to the issuance of the official warning, they will be of considerable value as an easily used and highly accurate forecasting aid. In addition, use of the bias correction further reduces the forecast errors by a significant amount. Until such time as prognostic SR steerings are available, the modified analysis SR steerings provide one of the best objective forecasting techniques available.

Several limitations of the SR steerings were noted during the 1967 season. If the tropical cyclone is of considerable size, greater than 800 mi. in diameter, it appears that the SR fields are not sufficiently smoothed. The end result is that the cyclone is steered around its own circulation. A second limitation occurs when the cyclone location is south of 10°N. lat. It is felt that the poor steerings resulting in these cases were associated with the treatment of the Coriolis parameter in the lower latitudes.

6. RECOMMENDATIONS FOR FURTHER STUDY

The following recommendations are suggested for further study: 1) Verify 48- and 72-hr. objective forecast techniques including a form of bias correction. 2) Verify Monterey steering predictions at other standard levels (850 mb. and levels above 500 mb.). 3) Stratify forecast verifications by latitude and/or storm direction of movement. 4) Develop a regression equation employing the Monterey steerings at several levels such as:

$$0.25(1000\text{-mb. steering}) + 0.45(700\text{-mb. steering}) + 0.30(500\text{-mb. steering}) = 24\text{-hr. forecast position.}$$

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